System Performance of an LTE MIMO Downlink in Various Fading Environments

Constantinos T. Angelis and Spyridon K. Chronopoulos

Department of Informatics and Telecommunications,
Technological Educational Institute of Epirus, Arta, Greece
`{kangelis,schronopoulos}@teiep.gr`

Abstract. This article presents simulation results for a realistic implementation of the downlink MIMO LTE Release 8 standard in fading environments. A 4x2 MIMO Channel configuration has been used as a basis in the simulation scenarios and various key characteristics of the MIMO channel and the LTE radio interface, including physical layer and radio resource management functions ware simulated and their impact on system performance is evaluated in both local and wide area scenarios. The results suggest that in practice multi-user LTE is able to support multi stream transmission with very high data rates, even for small hand held terminals. Moreover, the improvements of 4x2 MIMO transmissions for different system configurations are clearly shown over different MIMO channel environments. In depth analysis of the individual system characteristics indicates that these performance differences are due to rather uniform contributions from a set of distinctive features.

Keywords: LTE, Performance, MIMO, OFDM, dual-codeword, fading channel, Synchronization signals.

1 Introduction

The growing demands for broadband wireless data communications, in multihop capable interfaces, are becoming more and more intense due to their improvements of coverage and capacity. For these reasons they are proposed for the next generation cellular systems like 3G-LTE [1]. This has motivated many research efforts in the last years, puts high pressure on operators to increase the capacities of their networks and on the industry for enabling such an increase also in the long term future via more efficient and flexible communication standards. Long-Term Evolution (LTE) is an emerging radio access network technology standardized in 3GPP [1], that meets all the previous constrains, and evolving as an evolution of Universal Mobile Telecommunications System (UMTS). LTE uses Orthogonal Frequency Division Multiplexing OFDM as downlink air interface multiple access scheme [1].

OFDM, which is a multi-carrier modulation scheme, uses a set of subcarriers to transmit the information symbols in parallel over the channel. One of its main advantages is increased robustness against frequency selective fading and narrowband

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interference [2-5]. Efficient implementation of OFDM systems is based in the use of rather simple FFTs in both the transmitter and receiver. This characteristic makes such systems suitable for future high-datarate wireless systems [4-6]. Moreover the overall system reliability is increased with the use of multiple antennas in both the transmitter and receiver [7,8]. Despite these advantages, the simultaneous use of multicarrier modulations and multiple antenna systems with Spatial multiplexing and Transmit diversity schemes has a variety of challenges that still need to be validated experimentally [9].

Many researchers work on LTE systems. General LTE concept descriptions are available in [2-10]. In these papers, the focus is on key characteristics of the LTE radio interface. A set of such key characteristics are both qualitatively discussed and quantitatively evaluated in terms of downlink user data rates, spectrum efficiency generated by means of system level simulations and measurements. In [3] the performance of two dual-codeword SU-MIMO schemes, i.e. Per Antenna Rate Control (PARC) and Precoded MIMO (PREC) is studied in an OFDM deployment for LTE Release 6. In [10] some key characteristics of the LTE radio interface are compared to WiMax in 2 GHz, including physical layer and radio resource management functions, and their impact on system performance is evaluated. In [11] the principle coordination tasks of OFDMA resources in the singlehop and multihop case are discussed. In [12] downlink simulation results for a realistic implementation of the LTE standard are presented. In [13] a real implementation of a 4x4 broadband wireless MIMO-OFDM testbed based on an extension of the IEEE 802.11g/a physical layer (PHY) to multiple antenna scenarios is presented. Finally, in [14] a comparative performance analysis of the different families of solutions for the detection of Primary Synchronization Signals (P-SS) within LTE cell search procedure is proposed.

In this paper we investigate the impact of using synchronization signals (P-SS and S-SS), that are transmitted on each Tx antenna, in the FDD overall performance in both local and wide area scenarios and also for both Transmit Diversity and Open-loop Spatial Multiplexing transmission modes with 4 antennas in the transmitter and 2 antennas in the receiver. Frequency division duplex (FDD) is preferred for large area coverage and is the preferred mode for the LTE [1]. The novelty of the presented paper is the investigation of the use of synchronization signals (P-SS and S-SS) in fading environments for both in both local and wide area scenarios. These conditions mainly occur when the FDD OFDMA MIMO LTE systems are indented to be used in vehicular and urban environments, cases that are present in Ambient Assisted systems and applications. The rest of the paper is organized as follows: Section 2 describes the FDD MIMO LTE system level model; Section 3 presents an overview about the simulation model used for the investigation with description of the performed link and system level simulations; Section 4 presents the simulation results; and finally the conclusions are given in Section 5.

2 The FDD MIMO LTE Simulation Model

This section presents the simulation setup environment. The simulation results ware obtained with the Agilent Advanced Design System (ADS) [15]. We performed TDD downlink MIMO 4x2 coded measurements on fading channels for all the combinations of the parameters discussed bellow. Figure 1 shows a schematic diagram of the simulation model that consists in three main blocks: transmitter, channel and receiver chains.

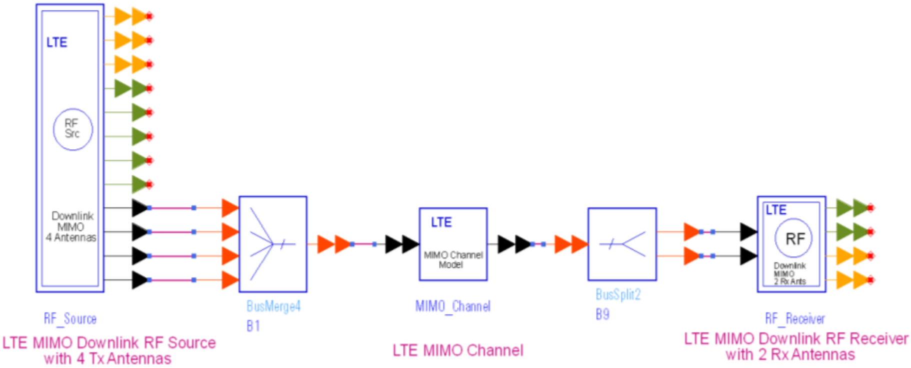


Fig. 1. The FDD MIMO LTE simulation model

Table 1. LTE System fundamental simulation conditions and parameters

Parameter	Value
Carrier Frequency	2.6 GHz
Bandwidth	5 MHz
Frame Mode	TDD Configuration
Oversampling	Ratio 2
Cyclic Prefix	Normal
Antenna Configuration	4x2
Number of code word(s)	2 for Spatial multiplexing, 1 for Transmit diversity
Number of layer(s)	2 for Spatial Multiplexing, 4 for Transmit diversity
Correlation	Low (α=0, β=0), Medium (α=0.3, β=0.9), High (α=0.9, β=0.9)

The signal source follows the definition of reference channel in A.3 of TS 36.101 [1] with the exception that no Physical Hybrid ARQ Indicator Channel (HARQ) transmissions are employed and a Bandwidth of 5 MHz is employed. The modulation types that we used in our simulation scenarios are (a) 5 MHz QPSK 1/3, (b) 5 MHz 16QAM 1/2 and (c) 5 MHz 64QAM 3/4. Transmit diversity and Open-loop spatial multiplexing transmission modes were used with 4 transmitter antennas and 2 receiver antennas. Fading channels following the definition in Annex B of TS 36.101 [1]. The channel settings that were used are [1]: Extended Vehicular A model with low Doppler frequency of 5Hz (EVA 5 Hz), Extended Typical Urban model with medium Doppler frequency of 70Hz (ETU 70 Hz) and Extended Typical Urban model with high Doppler frequency of 300Hz (ETU 300 Hz). The correlation matrix support was set to Low, Medium and High. Table 1 shows some of the most fundamental simulation conditions and parameters.

In MIMO systems there is correlation between transmit and receive antennas. For maximum capacity it is desirable to minimize the correlation between transmit and receive antennas. Three different correlation levels are defined in the LTE specification TS 36.101: (i) low or no correlation (ii) medium and (iii) high correlations. The parameters α and β are defined for each level of correlation as shown in Table 1. The channel spatial correlation matrix (R_{spat}) for the 4x2 case is defined as:

$$R_{spat} = R_{eNB} \otimes R_{UE} = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9^*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9^*} & \alpha^{1/9^*} & 1 & \alpha^{1/9} \\ \alpha^* & \alpha^{4/9^*} & \alpha^{1/9^*} & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix} \tag{1}$$

where R_{eNB} and R_{UE} are the independent correlation matrices at UE and eNodeB respectively.

Primary and secondary synchronization signals are transmitted in the downlink to enable the UE to acquire time and frequency synchronization with a cell. The primary synchronization signal (P-SS) identifies the symbol timing and the cell ID within a cell ID group, while the secondary synchronization signal (S-SS) identifies the cell ID group. The Primary and Secondary Synchronization Signals (P-SS/S-SS) are transmitted on all the transmit antenna ports. In LTE, 3 different P-SS are generated from a frequency domain Zadoff-Chu sequence, according to [1, 14, 16, 17]:

$$d_\mu(n) = \begin{cases} \exp\left(-j\dfrac{\pi\mu(n+1)}{63}\right) & n = 0,1,\ldots,30 \\ \exp\left(-j\dfrac{\pi\mu(n+1)(n+2)}{63}\right) & n = 31,32,\ldots,61 \end{cases} \tag{2}$$

where $d_\mu(n)$ denotes the P-SS and μ denotes the sequence root index, which is 25, 29, or 34.

Cell search procedure is an essential process that allows a mobile terminal to acquire time and frequency parameters and thereafter be able to demodulate downlink and/or to transmit uplink data. In LTE, this procedure is mainly realized through the broadcast of Primary Synchronization Signal (P-SS) and Secondary Synchronization Signal (S-SS). The Primary Synchronization Signals (P-SS) are used for the identification of the physical layer cell identity, while the Secondary Synchronization Signals (S-SS) are used for the identification of the physical layer cell identity group. Thus, knowledge of the P-SS and S-SS impact in the overall LTE Performance is helpful in alleviating the detection problems.

3 Results and Discussion

Performance of the simulated schemes is compared in terms of Tx and Rx Signal Spectrum, Complementary Cumulative Distribution Function (CCDF), BER and FER measurements. Simulations were made for both presence and absence of synchronization signals (P-SS/S-SS), which in the former case were used according to [14]. The Real and Imaginary part of the FDD Downlink LTE waveforms in the 4 transmit antennas that we used are shown in figure 2. For simplicity 1 Slot is shown. Figure 3 presents indicative Signal spectrums in the 4 transmit antennas and in the 2 receive antennas for $E_b / N_o = 20dB$. The modulation scheme in figures 2 and 3 is QPSK 1/3, while the correlation was set to medium.

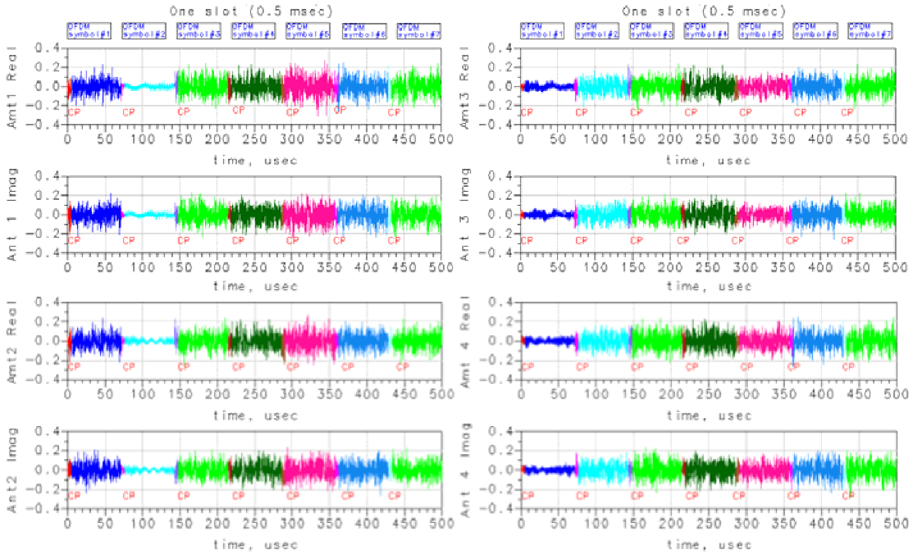


Fig. 2. Real and Imaginary part of the FDD Downlink LTE waveforms in the 4 transmit antennas

Fig. 4 shows Complementary Cumulative Distribution Function (CCDF) measurements of the TDD Downlink LTE signals in the 2 receive (Rx) antennas for (a) Spatial multiplexing and (b) Transmit diversity MIMO Mode for $E_b / N_o = 20dB$, medium correlation and for different MIMO channel models [1]: Extended Vehicular A model with low Doppler frequency of 5Hz (EVA 5 Hz), Extended Typical Urban model with medium Doppler frequency of 70Hz (ETU 70 Hz) and Extended Typical Urban model with high Doppler frequency of 300Hz (ETU 300 Hz). The modulation scheme is QPSK 1/3.

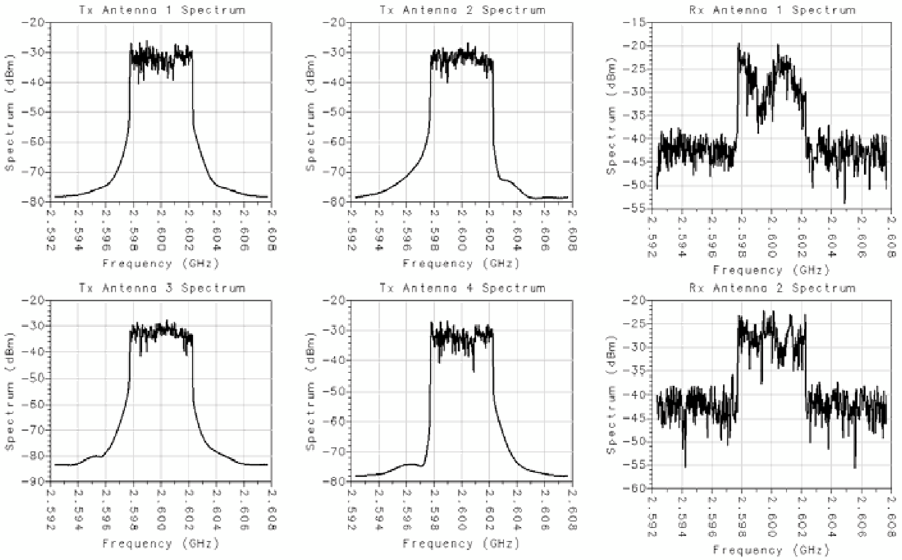
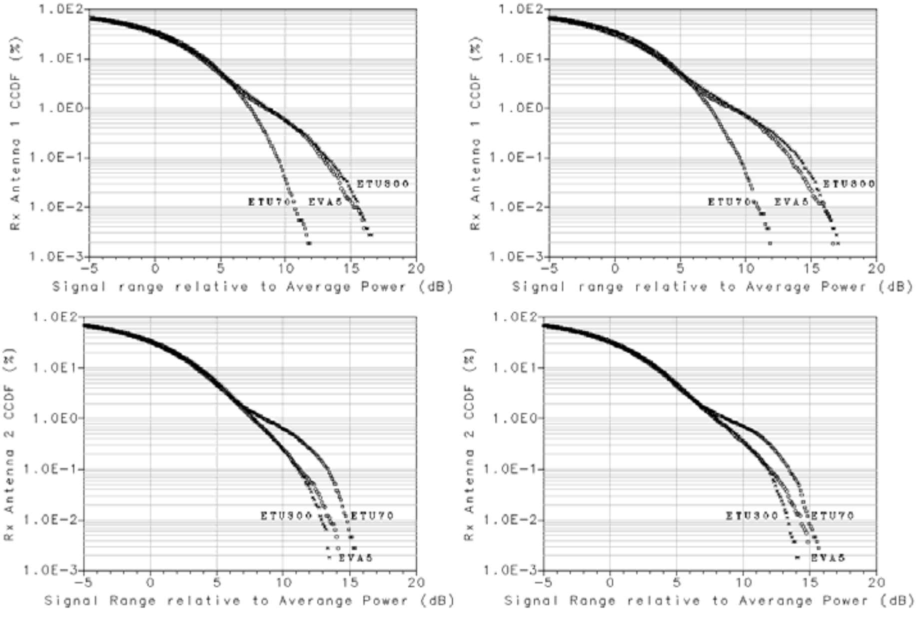
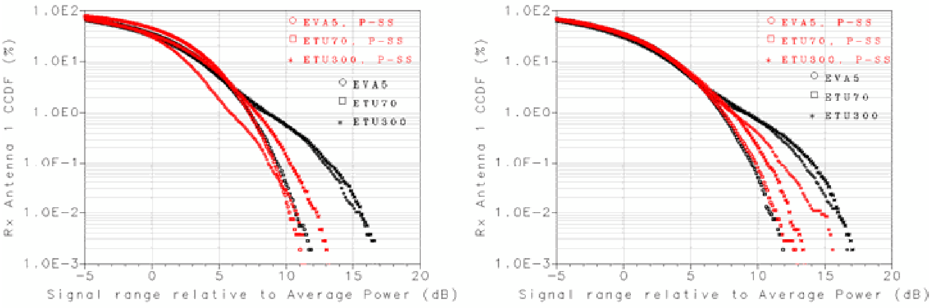


Fig. 3. Signal spectrums in the 4 transmit (Tx) antennas and in the 2 receive (Rx) antennas for $E_b / N_o = 20dB$



(a) (b)

Fig. 4. CCDF measurements of the TDD Downlink LTE signals in the 2 receive (Rx) antennas for (a) Spatial multiplexing and (b) Transmit diversity MIMO Mode for $E_b / N_o = 20dB$



(a) (b)

Fig. 5. CCDF measurements in different environments (EVA5, ETU70, ETU300) in the first receive (Rx) antenna for (a) Spatial multiplexing and (b) Transmit diversity MIMO Mode, with or without P-SS signals

Fig. 5 shows Complementary Cumulative Distribution Function (CCDF) measurements of the TDD Downlink LTE signals in the first receive (Rx) antenna for (a) Spatial multiplexing and (b) Transmit diversity MIMO Mode for $E_b / N_o = 20dB$, medium correlation and for different MIMO channel models [1]: (EVA 5 Hz), (ETU 70 Hz) and (ETU 300 Hz), when P-SS signals are transmitted or not. The modulation scheme is QPSK 1/3. As it is clearly seen, the use of P-SS signals affects the CCDF in the case of (EVA 5 Hz) and (ETU 300 Hz), while in the case of (ETU 70 Hz) the use of P-SS signals practically does not affect the CCDF. These results are in accordance with [4], where the WiMax IEEE 802.16-2005 system is studied.

4 Conclusion

In this paper the impact of using synchronization signals, that are transmitted on each Tx antenna, in the FDD overall performance in both local and wide area scenarios and also for both Transmit Diversity and Open-loop Spatial Multiplexing transmission modes with 4 antennas in the transmitter and 2 antennas in the receiver was investigated. Results show that, when QPSK 1/3 is used as modulation scheme, the use of P-SS signals affects the overall system performance when they are used in the case of Extended Vehicular A model with low Doppler frequency of 5Hz (EVA 5 Hz) and Extended Typical Urban model with high Doppler frequency of 300Hz (ETU 300 Hz), while in the case of Extended Typical Urban model with medium Doppler frequency of 70Hz (ETU 70 Hz) the use of P-SS signals practically does not affect the CCDF.

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